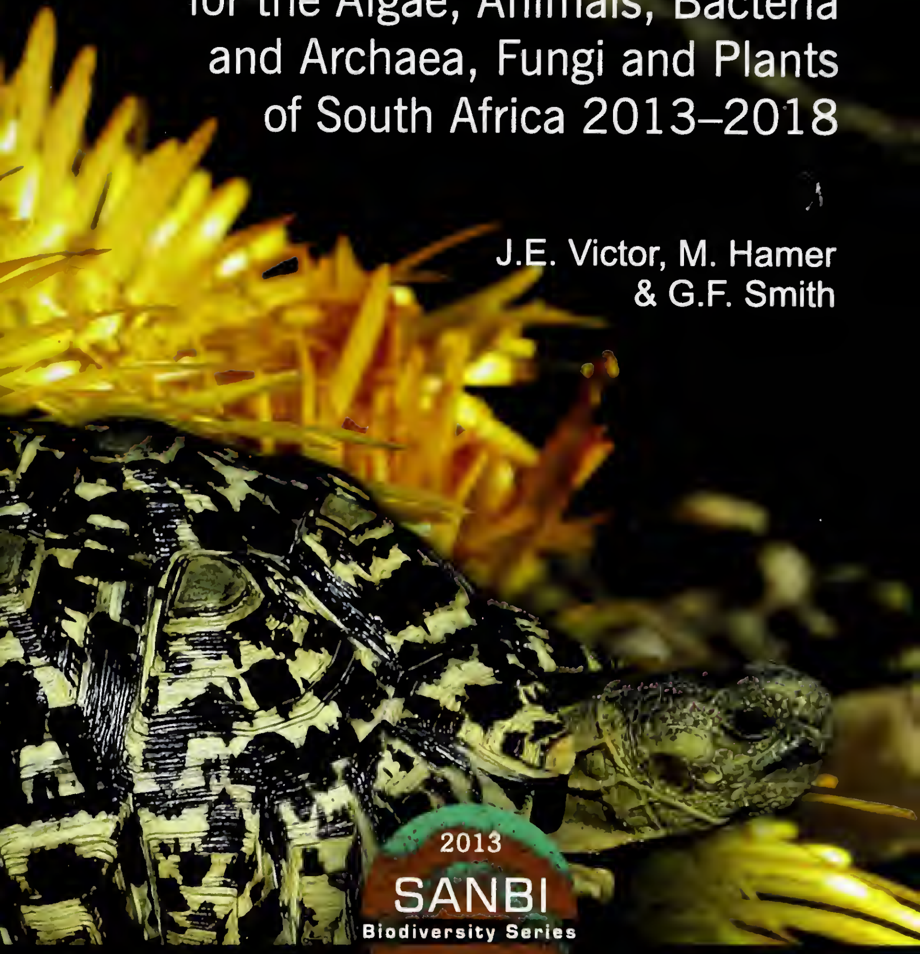
A BIOSYSTEMATICS RESEARCH STRATEGY

for the Algae, Animals, Bacteria and Archaea, Fungi and Plants of South Africa 2013–2018

J.E. Victor, M. Hamer
& G.F. Smith



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SANBI Biodiversity Series

The South African National Biodiversity Institute (SANBI) was established on 1 September 2004 through the signing into force of the National Environmental Management: Biodiversity Act (NEMBA) No. 10 of 2004 by President Thabo Mbeki. The Act expands the mandate of the former National Botanical Institute to include responsibilities relating to the full diversity of South Africa's fauna and flora, and builds on the internationally respected programmes in conservation, research, education and visitor services developed by the National Botanical Institute and its predecessors over the past century.

The vision of SANBI: Biodiversity richness for all South Africans.

SANBI's mission is to champion the exploration, conservation, sustainable use, appreciation and enjoyment of South Africa's exceptionally rich biodiversity for all people.

SANBI Biodiversity Series publishes occasional reports on projects, technologies, workshops, symposia and other activities initiated by or executed in partnership with SANBI.

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Chapter 1
INTRODUCTION

What is taxonomy?

South Africa has a proud history of taxonomic research endeavour across all the indigenous and naturalised biota present in the country. In the 17th and 18th Centuries most biological specimens collected in South Africa for taxonomic work found their way to natural history museums and herbaria in continental Europe and the United Kingdom, but during the past 150 years the development of local specimen preservation facilities saw research in this area expanding in the country. However, taxonomic research is often conducted in an explorative manner with inadequate regard for the needs of end-users, and gaps in the existing knowledge framework have largely not been considered. Taxonomy remains fundamentally important in all downstream biodiversity research, including several serious environmental issues such as the sustainable use of natural resources and spatial planning to protect ecological infrastructure. Globally, the importance of taxonomy has been recognised by way of the Global Taxonomy Initiative (GTI), one of the thrusts of the Convention on Biological Diversity (CBD), to which South Africa is a signatory. The CBD describes taxonomy as "...the science of naming, describing and classifying organisms. Using morphological, behavioural, genetic and biochemical observations, taxonomists identify, describe and arrange species into classifications, including those that are new to science. Taxonomy identifies and enumerates the components of biological diversity, so providing basic knowledge underpinning management and implementation of the Convention on Biological Diversity". Usually more broadly defined, 'systematics' and 'biosystematics' are nevertheless sometimes used interchangeably with 'taxonomy'. Regardless, this sphere of science essentially provides a fundamental understanding of, and information about, components of biodiversity. Taxonomy contributes to and is indispensable for all biological research, including enabling effective decision-making in conservation and the sustainable use of biodiversity.

This is the first ever comprehensive National Biosystematics Research Strategy that deliberately emphasises the research component of taxonomy. However, taxonomic research is inextricably linked to collections of preserved biological collections typically held in natural history museums and herbaria, as well as to the datasets that are derived from specimens held in these collections. Although this document therefore deliberately addresses the research component of biosystematics in South Africa, collections and data capture and dissemination are here identified as co-priorities for attention, especially in the case of animals and fungi, because of the dependence of research on these resources. This research Strategy recognises the challenges faced by collections, and derivative datasets are seen as a major output from taxonomy

that is needed by users of taxonomic information and so this has been included for animals. Additionally, both collections and datasets are included in the GTI list of priorities.

South Africa's biodiversity wealth

The latest estimate for the total number of species on Earth is 8.7 million, with 6.5 million species found on land and 2.2 million (about 25% of the total) dwelling in the ocean depths (Mora *et al*. 2011). The same study states that 86% of all species on land and 91% of those in the seas have yet to be discovered, described, and catalogued; even though over 1.2 million species have been described to date.

Why a strategy?

A co-ordinated Strategy for taxonomic research that addresses the needs of end-users will significantly improve the relevance and impact of research products delivered by taxonomists. The Strategy also serves as a basis for co-ordinating and promoting taxonomic research throughout South Africa, thereby providing leadership in this regard.

Further benefits of the Strategy are that it:

- Provides a shared vision to guide research.
- Sets and leads the biosystematics research agenda in South Africa by providing guidelines for research priorities.
- Communicates the value of taxonomic research to the public, academic institutions and funding agencies.
- Makes the most strategic use of limited resources for taxonomic research.
- Guides future decisions on capacity development, staff recruitment and training.
- Informs funding allocations for taxonomic research.
- Stimulates the implementation of and dissemination to stakeholders of priority research products.

Context for the strategy

At national level, the National Environmental Management: Biodiversity Act (NEMBA) No. 10 of 2004: Section 11, gives the South African National Biodiversity Institute (SANBI) the mandate to lead, through co-ordinating and promoting, taxonomy in the South African community. Internationally, governments of the world, through the CBD, have acknowledged the importance of taxonomy and the existence of a "taxonomic impediment" that frustrates the recording and sound management of biodiversity. This impediment refers to the knowledge gaps in our taxonomic system, the shortage of trained and skilled taxonomists and collections curators, and the crippling impact these deficiencies have on our ability to conserve biological diversity and to use and share the benefits derived from it.

Decision-makers need to know which species occur where to facilitate the establishment and wise management of protected areas and to enable sustainable land-use. It is also necessary to understand which species make up communities that collectively play an integral role in the functioning of ecosystems on which humankind and all life on Earth ultimately depend. Regulating and combating harmful invasive species is only possible if they can be distinguished from indigenous species. How can

the economic potential presented by the sustainable use of our biodiversity be unlocked if the diversity remains unknown? Taxonomy ultimately provides a fundamental understanding of the components of biodiversity that are necessary for effective decision-making about, among other things, conservation and sustainable use.

In this national and international context, this Strategy is intended to guide South African institutions that are involved in taxonomic research, aiming to ensure that the needs of end-users are addressed, so improving the relevance and impact of research products. At a broader national scale, the Strategy forms part of the National Biodiversity Research Framework that SANBI is developing for the country.

This is the first comprehensive Strategy produced for the major biota of South Africa. In botanical taxonomy previous strategic work focussed on setting priorities and criteria for decision-making on where research should be concentrated, but there have been no similar activities for other taxa.

Purpose of the strategy

The purpose of the Strategy is to provide clear guidelines to taxonomic researchers as to where to direct research effort and resources to maximise the benefits of research to society. The Strategy also clarifies the co-ordinating role with which SANBI is mandated.

Scope of the strategy

Taxonomic coverage: The Strategy deals with the taxonomy of living organisms. Three domains of life are recognised: the Bacteria, Archaea and Eukarya. Whereas Bacteria and Archaea each comprise a Kingdom of their own, Eukarya is divided into four kingdoms: animals, plants, fungi and protists. Viruses and subviral agents (e.g. prions) are not classified in a Kingdom as they are not considered to be living organisms, and for this reason they are excluded from the Strategy. A South African Strategy for the Palaeosciences has recently been developed and gazetted, therefore this strategy is confined to organisms currently in existence.

Since the diversity (how many?), richness (how much?), extent of previous attention received, and the existing and available capacity differ across different groups of organisms (even within Kingdoms), the approach for the strategy has been to deal with each major group separately.

Geographic coverage: Organisms occurring naturally and as introduced aliens in South Africa, including all its terrestrial, fresh-water and marine habitats, were considered in developing the Strategy. Living organisms do not observe political boundaries, and many taxa that occur in the country extend beyond its borders.

Timeframe: The main temporal focus of the Strategy is the next five years (2013–2018). The Strategy will be reviewed and revised after this 5-year period.

Developing and implementing the strategy

For SANBI the availability of a national Strategy for taxonomy is a step towards promoting and co-ordinating this type of research in South Africa and also fulfils at least some requirements of the GTI. Deliberate implementation of the Strategy is more challenging as the taxonomic community is spread across many different types of autonomous institutions including museums (at all three tiers of government, namely local, provincial and national), universities, national facilities and science councils, over which SANBI does not have authority. Monetary allocation to research in South Africa is a primary responsibility of the Department of Science & Technology, therefore the Strategy is intended to inform taxonomic research funding at a national level. Allocation of funding can therefore be influenced by giving preference to required outputs of the Strategy.

Challenges to biosystematics research presented by current trends

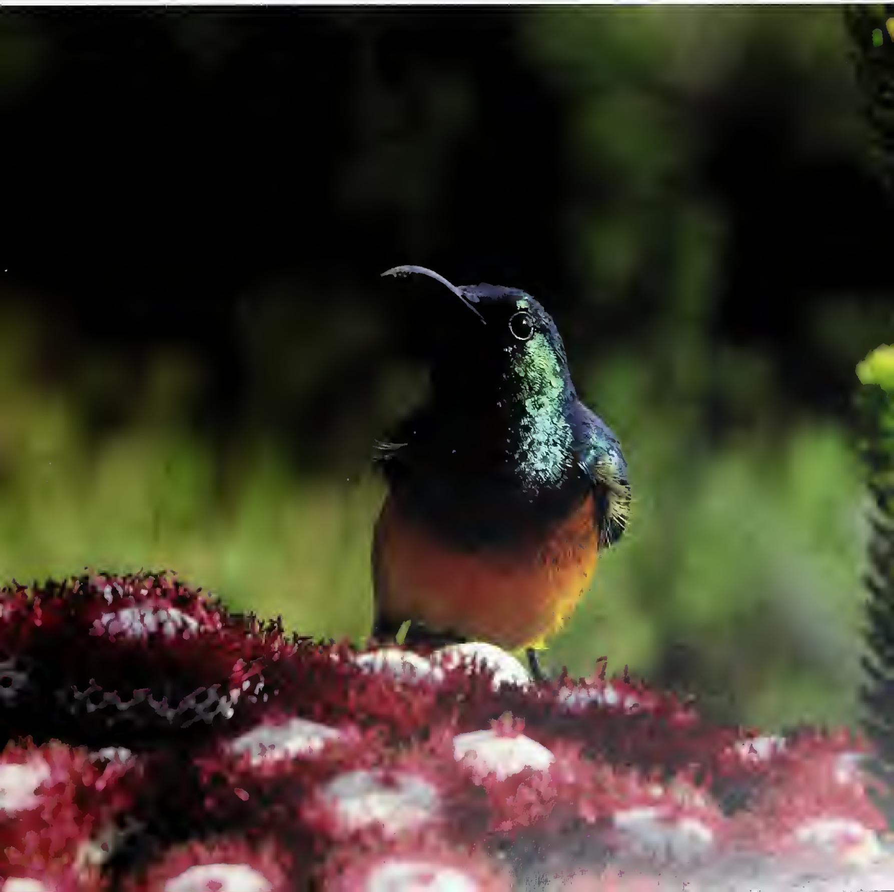
The main challenges relate to a disjunction between what is needed from taxonomists to address the taxonomic impediment and what research is done by taxonomists, lack of access to taxonomic information in a format and medium that serves a broad community of users of such information, lack of appropriate capacity, especially at natural history museums, and a lack of co-ordination of taxonomic activities and outputs in South Africa.

In most needs assessments done globally and by individual countries, the following are regarded as the main requirements of the users of taxonomic data:

1. Reliable identification of material/specimens (either as a service, or enabling this through the provision of user-friendly identification keys/resources)—*What is it?*
2. Accurate species occurrence and abundance data sets—*Where does it occur? / How many are there?* and *How is this changing / has this changed over time?*

3. Co-ordinated information about species, including classification, nomenclature and information such as functional role, threat status and importance to humans—*What is it called and what does it do?*

Answers to these questions are needed to enable countries, regions and organisations to manage and conserve biodiversity, which in turn will enable people to have sustainable livelihoods and so must be seen as priorities. Appropriate human capacity, access to collecting permits, and the maintenance of collections are supporting activities essential to the delivery of these three main needs, as well as for future research and the selective expansion of collections of preserved organisms.



Chapter 2
ALGAE

Prof. John Bolton (Department of Botany, University of Cape Town) & Janine Victor (Biosystematics Research and Biodiversity Collections Division, SANBI)

'Algae' is not a taxon, and what are considered algae by those studying them (phycologists) are evolutionarily, and hence taxonomically, enormously diverse. While algae are traditionally defined as non-vascular, photosynthetic organisms with simple vegetative and reproductive structure (Bold & Wynne 1985), there are exceptions; for example many of the dinoflagellates are non-photosynthetic. Algae are represented across the breadth of the eukaryotic domain, including representatives that are deeply rooted in branches that give rise to the land plants and to the animals.

Review of current status of algal systematics in South Africa

Bolton & Stegenga (2002) estimated there to be around 800 species of marine macro-algae recorded for South Africa; around 9.5% of the global total estimate. Therefore, in the unlikely circumstance that seaweeds can represent a guide to algal diversity in general, a very rough estimate of algal diversity in South Africa would be around 6 900 species. No attempt has ever been made to list or add up the numbers of algal species recorded in South Africa.

The only group of algae that can be considered to have been reasonably well studied in recent years are the marine macro-algae (seaweeds). A comprehensive document exists with descriptions and illustrations of seaweeds of the west coast (Stegenga *et al.* 1997), and a less comprehensive guide has been produced for seaweeds of the east coast (De Clerck *et al.* 2005). A website is under construction (R.J. Anderson, Department of Agriculture, Forestry and Fisheries (DAFF)) that will have descriptions and illustrations of seaweeds of the intervening south coast. An annotated checklist of seaweeds recorded for South Africa is therefore urgently needed.

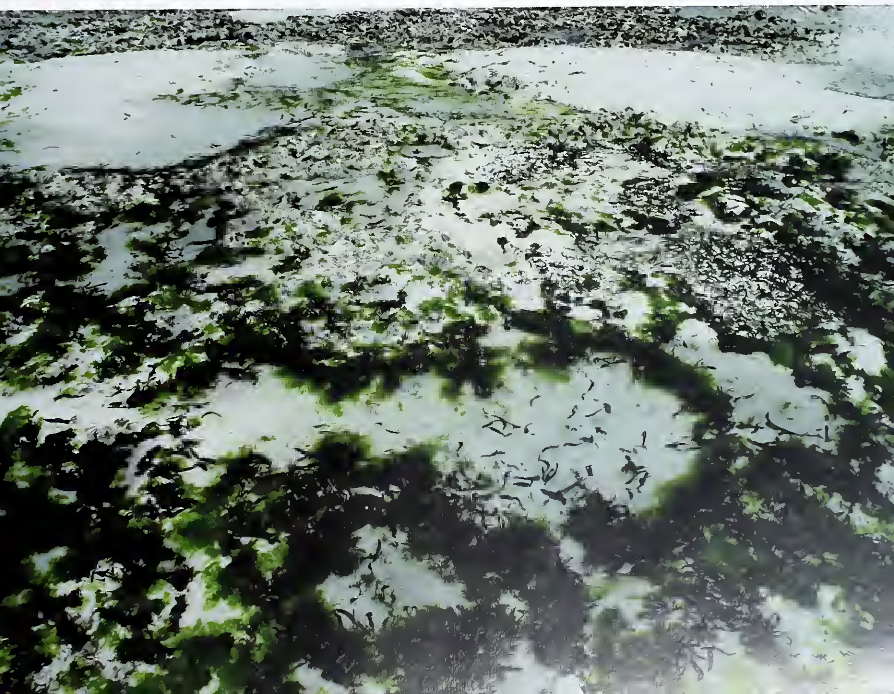
The diatoms were well studied in the past, but there is no checklist available for species that have been recorded in South Africa. Work has also been undertaken on inshore marine phytoflagellates. Most taxonomic investigations are as a result of serendipitous encounters with novel taxa or dealings with problem algae rather than due to in depth surveys, and nearly all have been limited to inshore waters.

Many records were made in the literature of freshwater algae many years ago (particularly in the 1930s and 1940s), but no attempt has ever been made to compile records of South African freshwater algae.

In South Africa, taxonomic work on algae is only carried out by a few academics and their students at universities, where all major algal collections are held. The majority work with marine macro-algae (seaweeds) and none of them is a full time algal taxonomist. There are growing collaborations with authors overseas who work on specific groups of algae.

Vision for the algae systematics research strategy

To document all existing literature records and specimens in collections of South African algae and to enhance and support taxonomic research on South African algae into the future.



Strategic objectives of the algae systematics research strategy

SO 1: Develop an inventory of all species recorded in the literature, with an online checklist as the ultimate goal.

SO 2: Develop a widely accessible online algal identification guide with descriptive information and keys.

SO 3: Develop capacity in taxonomic research on algae.

Activities to achieve objectives

SO 1: To collate and database taxonomic literature, develop a checklist, and liaise with SANBI to provide this as an online resource. A good starting point is a major literature-based algal website (www.Algaebase.org), managed by Prof. Michael Guiry (University College Galway, Ireland).

SO 2: To achieve an online Flora, the database (see SO 1) would need to be additionally populated with descriptions of all species, and these made accessible online.

SO 3: Initiate a research programme for postgraduate students addressing taxonomic problems, prioritising taxa of most relevance to society (i.e. economically and ecologically important taxa). Projects to develop electronic identification tools would need to be encouraged; and interns, postdoctoral fellows or students engaged to capture existing information into databases, including descriptions and images.

Chapter 3
ANIMALS

Prof. Michelle Hamer (Biosystematics Research & Biodiversity Collections Division, SANBI)

Review of the current status of animal taxonomy in South Africa

Animal diversity: South Africa has over 65 000 described species of animals, but it is recognised that as many as 80 000 remain to be discovered and described. Most animals are invertebrates, with the greatest species richness being represented by insects (>43 000 species). New animal species continue to be described at an increasing rate, with 3 668 new species described in the past decade.

Research capacity: Ninety-two researchers/academics contribute to animal taxonomy/systematics research in South Africa, and an additional 14 retired researchers continue to publish in the field. There is a marked skew in terms of taxonomic focus, with more taxonomists working on the <4 000 vertebrates species than on the >43 000 insect species. This translates to a ratio of taxonomists : known species number for vertebrates of 1:28, and for a major insect group, the Lepidoptera (butterflies and moths), of 1:7 000. The number of taxonomists based at museums has declined to 23, down from 62 in 1991. Age distribution of taxonomists indicates that there will be at least 15 vacancies from retirements in the next five years. A major concern is that there will potentially be only a single entomologist at a university to train postgraduates in insect taxonomy within the next five years.

Research collections: South Africa has vast research collections comprising over 15 million animal specimens in 23 institutions and 75 collections. Major challenges for collections relate to: (i) the governance of the collections, with most of the large institutions falling under national and provincial departments of arts and culture, which have no mandate for the curation of biological collections, and, (ii) the use and accessibility of the collections. The collections are viewed as being of value only to a small group of specialists, and the use of data and specimens for a range of decision-making and research activities is inadequately promoted.

Databases: The data associated with more than 6 million specimens in the research collections remain to be captured on databases, and a relatively small amount of

data (approximately 600 000 records) from the collections has been provided to the South African Biodiversity Information Facility (SABIF) for dissemination and application in land use planning.

DNA barcoding is a technique that helps taxonomists with hard-to-identify specimens or parts of specimens, and is an innovative way for non-experts to identify biological material. While there has been some criticism of barcoding and it does not work for all taxa, it has been adopted by many countries and researchers, and its use has been proven in a range of applications. Barcode sequences are lodged and made accessible through the Barcode of Life Database (BOLD). By July 2012, 8 499 records of animals from South Africa were publically accessible in the BOLD database, but only 834 of these were identified to species level, which somewhat limits the current usefulness of the system.

Research publications: An analysis of research publications by animal taxonomists nationally over the past just-more-than-three decades, shows they have described less than a third of the new species discovered in South Africa during this time frame. Each taxonomist has described less than one species per year

on average. There has been a solid output in terms of publishing high quality molecular phylogenetic studies and this area could be considered a current strength. The bulk of this type of research, however, does not directly address the taxonomic impediment.

Given the diversity of animals in South Africa, and the financial and capacity constraints, it is impossible to deliver on the three needs for all animal species, and prioritisation, based on feasibility (including expertise available and the current state of knowledge relative to the diversity) and the rationale for taxonomic study (i.e. is the taxon of major importance in ecosystem functioning or a keystone taxon or of economic value?), is critical.

Vision for animal taxonomy in South Africa

Consolidation, co-ordination and dissemination of comprehensive taxonomic information for use by a wide range of stakeholders, and the generation of new knowledge in line with national priorities.

Strategic objectives for achieving the Vision

Four strategic objectives that relate directly to the core work of taxonomists are:

SO 1: To develop and make accessible accurate and comprehensive primary data sets for specimens of selected taxa for use in land-use planning, species threat assessments, biodiversity monitoring and research relating to global change impacts on biodiversity.

SO 2: To carry out taxonomic research that is aligned with the needs of major initiatives and that is integrated into broader research programmes to ensure that taxonomy delivers useful and used knowledge.

SO 3: To develop identification tools for taxa of major concern for conservation, sustainable use and the management of invasive and pest species, and disease vectors. This includes the development of a DNA barcode reference library for the priority species.

SO 4: To develop capacity to enable taxonomists to contribute to the broad dissemination of their outputs and to develop new capacity in line with identified priorities.

Four additional objectives deal with outputs that may not be considered as being the primary work of taxonomists, but their contributions to and participation in the activities are essential.

SO5: To provide a complete and regularly updated checklist of animals in South Africa, including classification, synonyms and local names that are publically accessible through the internet.

SO6: To co-ordinate and disseminate existing foundational information for priority species.

SO 7: To initiate discussions on the recommendations made in the National Research Foundation (NRF) report on the status of research collections of preserved animals in South Africa.

SO 8: To explore mechanisms for enabling access to collecting permits so that this is not a major impediment to the exploration of animal diversity in South Africa.

Priority activities required to achieve the strategic objectives [and responsible organisations or communities]

SO 1: Primary datasets

- Ongoing expansion and updating of taxonomy for existing comprehensive datasets that have been compiled (reptiles, butterflies, amphibians, spiders) or that are currently underway (mammals, line fish, dung beetles) [SABIF in collaboration with data owners, taxonomists].
- Development of additional comprehensive datasets for taxa including arachnid orders, dragonflies, bees, and freshwater and marine invertebrates [SABIF, taxonomists, data owners]. Compile and disseminate a list of datasets and information about these (i.e. metadata) in order to co-ordinate activities [SABIF].

SO 2: Taxonomic research

- Develop and implement projects that are of direct relevance or that are integrated into broader projects in the fields of global change, ecosystem functioning and the bio-economy, which are currently receiving both national and international attention [funding agencies, taxonomists].

- Use these projects as models and for the promotion of taxonomy to funders and decision-makers to illustrate the value of taxonomy [SANBI, taxonomists].

SO 3: Tools for identifying species

- Determine existing projects and resources for the identification of priority taxa and categories of animals; identify gaps and develop a plan for addressing these and for providing access to those that are already developed [SANBI, taxonomists].
- Provide an open access internet platform for the submission of identification keys for the animals of South Africa, and ensure that these are arranged and accessible in a logical and user-friendly way [SANBI].
- Provide a list of all species and localities for which material has been barcoded, and a list of those species that are a priority for getting material barcoded [SANBI, taxonomists].

- Initiate project(s) for sampling and submitting specimens from priority taxa and categories for barcoding to expand the barcode reference library [SANBI, taxonomists].
- Explore innovative mechanisms for the documentation, description and identification of species [SANBI, taxonomists, funding agencies].

SO 4: Capacity development

- Develop skills of taxonomists to enable them to submit material for barcoding, to use the BOLD database, and to use other new technologies or approaches associated with the generation, co-ordination and dissemination of taxonomic data [SANBI, taxonomists, funding agencies].
- Develop capacity for priority taxa through the training of M.Sc. and Ph.D. students. Where appropriate expertise is not available in South Africa, it may be necessary to send students overseas to work with experts on South Africa's fauna, or to bring internationally-based experts to South Africa where they could then also contribute more broadly to projects [taxonomists].
- Consider the involvement of 'citizen scientists' in exploring and documenting South Africa's biodiversity [SANBI, taxonomists, citizen scientists and relevant societies].
- Establish links with international taxonomists who can contribute to documenting South Africa's biodiversity and to capacity development where expertise does not exist locally [SANBI, taxonomists].

SO 5: A checklist of South Africa's animal species

- Establish and populate a website for dissemination of existing checklists [SANBI].
- Compile checklists for taxa where these do not yet exist using the literature and input from taxonomists nationally and globally [SANBI, taxonomists].
- Regularly update and maintain existing lists [SANBI, taxonomists].

SO 6: Compilation and co-ordination of species information

- Identify an appropriate mechanism for the co-ordination and dissemination of species pages, either through a South African website, or through the Encyclopedia of Life [SANBI].
- Provide access to species page templates and lists of species for which pages are required as a priority [SANBI].
- Initiate the compilation of pages, and disseminate these through a website as soon as they have been compiled [SANBI, taxonomists].

- Develop a process for submission of additional information, and for review and comments to continually improve the quality of information disseminated [SANBI].

SO 7: Research collections

- Hold multilateral discussions between relevant government departments to initiate a solution to the existing governance challenge [SANBI, NRF].
- Explore an open access policy for providing data to users. Mechanisms for monitoring the use of data should also be explored: showing use is critical in motivating for the investment in these resources [SANBI, SABIF, collection institutions].
- Ensure that the loss of collections is minimised. Develop strong plans that prioritise activities that are essential to securing the collections [collection institutions].

SO 8: Collecting permits for taxonomic research

- Establish a list of *bona fide* researchers that is accessible on the internet and promote this amongst conservation authorities to assist with decision-making regarding the issuing of permits [SANBI, taxonomists].
- Explore other mechanisms to streamline the permitting process to enable the exploration of South Africa's biodiversity [SANBI, permit issuing authorities].

Chapter 4
BACTERIA AND ARCHAEA

Prof. Fanus Venter (Department of Microbiology and Plant Pathology, University of Pretoria) & Janine Victor (Biosystematics Research and Biodiversity Collections, SANBI)

Grouped together, the bacteria and archaea (from here on referred to collectively as "bacteria") are the most abundant organisms on Earth, forming the largest component of the earth's biomass and genetic diversity. Bacteria play a crucial role in ecosystems, such as in nutrient cycling, primary production oxygenic photosynthesis, soil health and biodegradation. Bacteria play an essential role in animals (including humans) for digestion of food, protection against pathogens, vitamin production and disease resistance. In plants, bacteria contribute to growth promotion, nitrogen fixation, bioactive compounds and bio-control. They are also widely used in industry for food preservation and during the production of therapeutic proteins.

Only a small fraction of bacteria are pathogenic to humans, plants or animals. Of the more than 1 900 described bacterial genera (Euzeby 2013), only about 80 are known to contain human pathogenic species (Versalovic 2011). Despite the limited number of pathogenic bacterial species, they have significant economic impacts and the bulk of the available research funding is directed towards studying the systematics and epidemiology of these pathogens. Studies focusing on other environments where most of the world's bacterial diversity resides remain underfunded.

Bacteria are referred to obliquely in NEMBA, in that SANBI "may establish, maintain, protect and preserve collections of animals and micro-organisms in appropriate enclosures". This is in no way a unique situation and only indirect references to bacteria can be found in the biodiversity strategies of other countries. For example, in the Australian Biodiversity Conservation Strategy, one of the best documented and advanced strategies, the decision was taken not to focus on organisms *per se* but to rather deal with them in the context of ecosystems (Natural Resource Management Ministerial Council 2010).

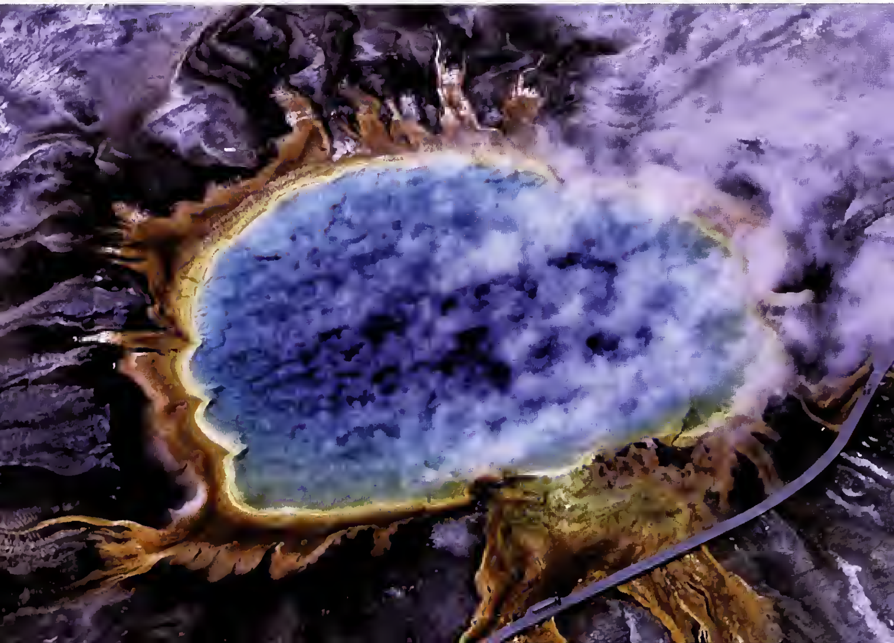
Opposite: a natural hot water spring, approximately 75 × 91 m in size. Deep blue water in the centre is surrounded by mats of brilliant orange algae and bacteria. The colours vary according to the ratio of chlorophyll to carotenoid molecules produced by the organisms. During summer the organisms produce less chlorophyll, which causes the mats to appear yellow, orange and red. In winter, when sunlight is weaker and microbes produce more chlorophyll, the mats appear dark green. Source: http://en.wikipedia.org/wiki/File:Grand_prismatic_spring.jpg.

Review of current status of bacteria and archaea taxonomy

Currently there are about 12 900 formally described species of bacteria globally (Euzeby 2013), but it is estimated that there could be between 1 and 10 million species (Curtis *et al.* 2006). The prevailing hypothesis is that some bacterial species are cosmopolitan while other species or groups may be restricted to specific environments (Ramette & Tiedje 2007).

The focus of many initiatives for funding to support taxonomy has mainly been on eukaryotic organisms with little or no attention to the domains of bacteria and archaea (Woese *et al.* 1990). This has been a major criticism (Griffith 2012) as these domains represent the 'unseen majority' of life on Earth (Handelsman 2004).

One of the reasons why bacteria have often been overlooked in biodiversity programmes with a conservation focus, is the flawed perception that all bacteria are omnipresent, highly redundant and unlikely to be at risk to become extinct (Fierer 2008). This perception is strongly driven by Baas Becking's paradigm "everything is



everywhere but the environment selects" (Baas Becking 1934). However, it has been found that there is a clear sign of regional endemism for some groups of bacteria and they should be included in conservation strategies (Griffith 2012).

Implementation challenges

Nationally there is no current governmental capacity or legal framework to deal specifically with bacteria. There are currently only a small number of active South African bacteriologists (≤ 15 academics at seven universities) that have recently published studies on the taxonomy or diversity of bacteria. Bacterial systematics is not the sole focus area of any of these academics and several of them are already over 50 years of age.

Proposed biosystematics research strategy for bacteria and archaea

The proposed strategy for bacteria and archaea taxonomy aims to assess the existing capacity and resources in South Africa, propose infrastructure to collate taxonomic and associated information, identify gaps and priority areas for research, and to propose a means to achieve this.

SO 1: To document new species of bacteria that may represent a unique genetic resource for the country

As the national strategy has a strong focus on the unique biodiversity of South Africa, three niches/environments known to potentially harbour 'endemic' bacteria will form the initial focus of the programme. These niches were selected based on the potential benefit these endemic bacteria could have to society. They are:

- *Indigenous plants harbouring beneficial bacteria:* The nitrogen fixing *Burkholderia* species associated with legumes in the Cape Floristic Region have great potential as robust inoculants in acidic soils and would be able to outperform the current commercial inoculants as they would be able to cope better with the increasing temperatures as a result of climate change.
- *Indigenous invertebrates harbouring symbiotic bacteria*: Many of the symbiotic actinomycetes associated with invertebrates such as termites and mites have been shown to produce unique antibiotics that could be used to treat both bacterial and fungal infection.

- *Unique ecosystems e.g. hot springs, deserts, deep mines and traditional fermented foods*: Several unique enzymes and metabolites are excellent examples of the commercial and scientific benefit that could be obtained from the unique bacteria present in these environments.

SO 2: To provide checklists and maintain databases or links to information on bacteria of economic importance for South Africa

Human, animal and plant diseases have a large impact on the economy in South Africa and the primary focus of this objective is to create checklists of pathogenic and other economically important bacteria previously reported for South Africa. It is envisaged that these checklists will be used by the various government departments such as Department of Health and Department of Agriculture, Fisheries and Forestry for dealing with import permits and quarantine measures. It will also be of benefit to plant pathologists, pathologists in general, veterinarians and farmers.

A book capturing this information for bacterial plant diseases in South Africa already exists (Coutinho *et al.* 2009). There is a need to convert this information to a searchable and regularly updated database. Students/interns can be employed to convert this to an online database.

Various researchers in South Africa work on bacteria that produce novel secondary metabolites and/or enzymes. It would be of benefit to these researchers as well as the industries involved to have a database of South African strains able to produce beneficial compounds such as secondary metabolites, unique enzymes, pigments, antioxidants and biosurfactants.

SO 3: To create a database of relevant information and links to information that could guide identification

Many microbiologists without an interest in bacterial systematics need to identify bacteria on a regular basis. To assist these end-users of the taxonomic data, a database will be created that will provide standard operating procedures, links to important websites (e.g. RDP, All Species Living Tree project, LPSN) as well as a list of the latest references works that can be consulted (e.g. *Prokaryotes*; *Bergey's Manual*) The database will also provide information on where bacterial cultures originating from South Africa can be obtained from recognised national and international culture collections.

SO 4: To promote research investigating the impact of bacteria on biodiversity, conservation and the functioning of ecosystems

The primary aim of this programme will be to ensure that studies dealing with biodiversity and ecosystem health include a bacterial component. This will be achieved by

providing information on funding opportunities, as well as the initiation of new joint research projects addressing issues such as the role of bacteria in the radiation of plant diversity or the impact of bacteria on ecosystem services and diversity.

SO 5: To establish the South African Bacterial Systematics Network: a network of researchers interested in bacterial systematics and diversity

The proposed strategy will not succeed unless the research community take responsibility for the promotion and implementation of this strategy. The proposed network will provide a forum for interaction, discussion and exchange of information. It can also assist with the co-ordination of effort to secure funding for research and the development of capacity. This forum should be linked to the existing societies such as the South African Society for Microbiology and the Southern African Society for Systematic Biology.

Paenibacillus dendritiformis colony. Image: Prof. Eshel Ben-Jacob, Tel-Aviv University, Israel. Source: Wiki Commons.

Chapter 5
FUNGI

Compiled by the South African Fungal Diversity Network[1]

Fungi comprise a unique group of organisms that occur in all habitats including soil, air, freshwater, marine sediments and on or inside the tissues of plants and animals and even other fungi. They include organisms commonly known as mushrooms, truffles, yeasts, rusts, smuts and moulds. Fungi are generally defined as being eukaryotic, heterotrophic, absorptive organisms that develop diffused, branched, tubular bodies and reproduce by means of spores (Shenoy *et al.* 2007). In addition to those organisms that clearly fit this description are others that have fungus-like properties, but that are not typical fungi.

In terms of this strategy, in addition to the organisms included in the Kingdom Fungi, the following groups that are not included in the Fungi, but which are traditionally studied by mycologists are also considered:

- *Lichens*, which are organisms representing an obligate symbiotic relationship between a fungus and a photosynthetic partner, which is usually a green algae or a cyanobacteria. Lichens occur in many habitats and have potential as indicators of air pollution, ozone depletion and toxic contamination.
- *Slime moulds*, a group comprising three major groups, plasmodial slime moulds, cellular slime moulds and protostelids (amoebae producing spores). Slime moulds usually exist as single-celled organisms (amoebae-like), but the cells can congregate and function as a single body to produce spores. They contribute to the decomposition of dead vegetation, and feed on bacteria, yeasts, and fungi.
- *Stramenophiles* are eukaryotes that comprise two major groups, the algae and colourless, fungus-like taxa. The algae are dealt with separately in another section of this strategy, but the other colourless, more fungus-like groups include taxa of economic and conservation importance, such as the late blight organism (*Phytophthora infestans*) responsible for the Irish famine and still causing major crop losses internationally, the related jarah dieback organism (*Phytophthora cinnamomi*) responsible for serious epidemics of both natural vegetation and

[1] This strategy was developed based on input from a workshop held at SANBI, Pretoria on 31 January 2013. Participants: Prof. K. Jacobs (Stellenbosch University), Prof. J. Dames (Rhodes University), Prof. E. Steenkamp, Dr W. de Beer, Dr S. Marincowitz (FABI, University of Pretoria), Dr M. Gryzenhout, Prof. G. Marais (University of Free State), Prof. J. Coetzee (Cape Peninsula University of Technology), Dr I. Rong, Dr A. Jacobs (ARC, PPRI), Ms J. Victor, and Prof. M. Hamer (SANBI). Additional input has been received from Dr A. Wood (ARC, PPRI) and Dr H. Vismer (MRC, Promec Unit).

tree crops internationally, and several groups that are parasitic on a range of animals and plants.

Fungi are critically important; most are terrestrial organisms that are symbionts of most plants, recyclers of nutrients and minerals, pathogens of plants and animals, bio-control agents, food sources for humans and other animals, and some are a source of valuable chemical products used in industries such as pharmaceuticals, biofuels, and food and beverage processing (Global Biodiversity Sub-Committee (GBSC) 2007).

Despite their importance, fungi are usually overlooked in biodiversity and taxonomy initiatives and activities, and they are not well known amongst scientists in general and, apart from those groups that are commonly used as food, by the general public. The main reason for this is that many fungi are microscopic and/or occur in habitats where they are not easily seen, such as in the tissues of other organisms or in the soil.

Based on the commonly-cited estimate of 1,5 million fungal species, only 100 000 are described and at the current rate of species description, it should take another 1 170 years to complete the global fungal inventory (Hibbet *et al.* 2011). With the declining capacity to document and describe the world's fungi, achievement of this aim is even less feasible.

When fungi are active in the environment, they consist of a mass of filaments (mycelium) of such extremely simple forms that it is impossible to identify to which species it belongs using what can be seen with the naked eye. The reproductive structures observed on the host material or on synthetic media have formed the basis of fungal classification, but these provide only a limited number of characters. Currently the integrated approach for fungal classification incorporates these morphological characters as well as phylogenetic relatedness amongst species based on gene sequences.

Review of current status of fungal systematics in South Africa

The South African indigenous fungi have generally been neglected by taxonomists. Better studied fungi include phytopathogens, especially on commercial crops, medically important fungi, mycotoxin-producing fungi and food-associated fungi. Poorly studied fungi include those associated with indigenous plants, soil fungi, especially mycorrhizal fungi (those associated with the roots of vascular plants), airborne fungi that may be important in human health, insect-associated fungi, freshwater and marine fungi and fungi in extreme environments.

Crous *et al.* (2006) stated that very few habitats and ecological niches in South Africa have been explored in terms of fungi. They estimated, based on the general

trend in ratio of plant to fungi species of 1:7, that the number of fungi species nationally could be at least 171 000 species, a number which excludes the species associated with insects and many other ecological niches. Given the conservative predicted number of species, it is staggering that only 780 new species of fungi have been described from South Africa (Crous *et al.* 2006). This is probably a result of the indigenous fungal diversity not being considered as a research priority and virtually all resources, especially over the last 50 years, having been directed towards economically important species in South Africa. The origin of many of these species is unknown.

The number of researchers in South Africa who are actively working on fungal taxonomy, which includes documenting and describing species, is very small and comprises about 20 individuals. Not all of these researchers devote all their time to this type of taxonomy, and most of them are also involved in other aspects of research on fungal biology or evolution. There is only one researcher based at an institution overseas who makes a major contribution to documenting fungal diversity in South Africa.

Most of the researchers are based at universities, with two active research groups outside such institutions (at the National Collections of Fungi at the Plant Protection Research Institute (PPRI) of the Agricultural Research Council (ARC) and the PROMEC Unit of the Medical Research Council). A major constraint in terms of increasing capacity for fungal taxonomy is the lack of job opportunities, which means that it is difficult to encourage even those interested in the discipline to focus studies in this area. During 2012, about eight postgraduates who were studying fungi were including aspects of taxonomy in their projects.

There are a number of global databases that co-ordinate taxonomic information, particularly classification, nomenclatural changes and description of new taxa for fungi. Two gaps in the existing data have been identified: (i) the need to update host plant names, and (ii) co-ordinated biological information for species. There is currently no online taxonomic resource for South African fungi.

Given the enormous gaps in knowledge about South African fungi, and the very limited available resources in terms of capacity and funding to research these organisms, the objectives of this strategy focus on what can be achieved and which activities are most critical. Prioritising specific taxa for study is not necessary as groups of economic relevance are already prioritised by employers and research funders.

The main challenges for fungal taxonomy are as follows:

- Lack of job opportunities for postgraduates trained in fungal taxonomy.
- Fragmentation and lack of collaboration between researchers in South Africa.
- Lack of awareness and appreciation of fungal diversity and the importance of fungi in ecosystems and the economy amongst the public, funding agencies, and scientific institutions.
- Lack of opportunities (time, funding, projects) to explore, document and describe indigenous fungi.

While having appropriate capacity for both taxonomic research and collections management is critical, the lack of available posts for specialists in these fields means that it would not be strategic to attempt to increase current efforts to develop capacity. An adequate number of postgraduate students are currently being trained relative to opportunities for employment and so no specific objective is required at this stage. The situation will need to be reviewed in the future.

Vision for the fungal taxonomy strategy

To facilitate, co-ordinate and promote (i) the exploration and documentation of fungal diversity, (ii) collections, and (iii) awareness of fungal diversity and relevance in South Africa

Strategic objectives

SO 1: Increase communication and interaction between fungal taxonomists to promote collaboration, especially in terms of exploring South African fungi, and to ensure that fungal diversity and taxonomy are represented in relevant biodiversity forums and decision-making processes and are part of broader biodiversity initiatives.

SO 2: Increase the profile of fungal taxonomy by including fungi in a national checklist of South African biodiversity, provision of relevant priority species information for open dissemination, and in the International Barcode of Life project.

SO 3: Increase representation across taxa in collections and ensure long-term security of material and data and provide access to this.

Activities to achieve strategic objectives:

SO 1: Networking and communication

- Establish a South African Fungal Diversity Network.
- Develop a list server that enables members of the network to provide information on research being done, field trips, material for sharing, funding and collaboration opportunities, and new findings.
- Organise regular meetings to promote interactions and identify key activities and opportunities.
- Represent the fungal taxonomy community on relevant committees or at forums dealing with biodiversity/taxonomy/collections.

SO 3: National collections

- Circulate a statement that promotes the National Collections as the recognised national facility for both preserved and culture fungal collections to ensure that unused material, student material and collections at risk are deposited and secured.
- Develop a set of standards and requirements for material to be deposited and vouchered in the National Collections and promote this amongst researchers.
- Formalise the arrangements for establishing a mycorrhizal collection at Rhodes University that will eventually be deposited in the National Collections.

- Track South African material vouchered in overseas institutions and link these to publications.

A long-term objective should be to expand the National Collections of Fungi under the custodianship of the ARC to establish a centre for fungal diversity exploration. This type of facility is essential to developing a better understanding of fungi in South Africa within a reasonable timeframe, but it would require considerable resources that would be difficult to access at this stage. Over the next five years, the strategy should be to explore possible mechanisms for developing such a centre.

Chapter 6
PLANTS

Janine Victor (Biosystematics Research and Biodiversity Collections, SANBI)

Most plant taxonomic research aims towards revisions of taxonomic groups, or other similar compilations (such as conspectuses, Floras, synopses and monographs). These products provide answers to the questions as to what a plant is, what it looks like, and where it grows. Another primary objective of taxonomy is to develop a natural and predictive classification system that reflects evolutionary relationships among plants. To achieve this, results from molecular studies are integrated with other sources such as anatomical, cytological, cytogenetic, and palynological studies.

Bringing together the needs of end-users and current trends in plant taxonomic research, in conjunction with gaps in taxonomic knowledge, informs the priority areas for taxonomic research in South Africa. These focal points form the strategic objectives that are required and determine which research programmes should be established. In addition, the way in which research is conducted can be enhanced so as to add value to the outputs, ensuring that they are not only relevant to scientific end-users but also have impact on and benefit to society.

Review of current status of plant taxonomy in South Africa

Botanical exploration of South Africa started early in the 17th century and there is an extensive amount of literature available, including many Floras and revisions published in a diverse array of journals and books. There are *ca.* 20 000 indigenous and naturalised plant species in South Africa. Major plant collections (i.e. more than 100 000 specimens) are housed in eight herbaria throughout the country, the largest of which is SANBI's National Herbarium with approximately 1 200 000 specimens. There are an additional 24 smaller local herbaria in the country (Smith *et al.* 1999). SANBI is therefore the major employer of plant taxonomists at its three herbaria in the country, with a staff component of approximately 35 technical staff and scientists curating the collections and some doing research. There are also about 20 plant taxonomists at universities around the country, who teach taxonomy and supervise the few postgraduate students that specialise in taxonomic research. SANBI also has a comprehensive database, which is able to provide information such as the national

checklist, checklists of any region or families, or of historical collections from particular areas. Some of this information is available online (www.sanbi.org.za) and other information is available on request from SANBI.

Vision for the plant research strategy

To document and provide predictive classifications for South African plant species, enabling users to identify and access knowledge about them, so that all can understand, conserve and benefit from biodiversity.

SANBI's specimen database with collection information for over 1.1 million plant specimens was interrogated using 'indicators' to reveal problematic plant groups and

thus possible gaps in taxonomic knowledge. These were used to inform where priority research activities should be aimed.

Strategic objectives and programmes of the strategy

The strategic objectives for the Biosystematics Research Strategy for plants are to:

SO 1: Produce an online electronic flora (e-Flora) of South African plants by 2020.

SO 2: Revise genera that are in need of revision.

SO 3: Resolve isolated taxonomic problems in species of conservation importance.

Activities required to achieve the strategic objectives

SO 1: e-Flora of South Africa

Produce family treatises for those families that have not yet been completed

Family treatments (such as Floras) of certain groups that are difficult to identify are of particular importance and should be prioritised, as well as those with taxonomic problems (Victor & Smith 2011) (Figure 1) and those that have not been treated.

Complete all regional floras for South Africa by 2018.

Completion of the regional floras by SANBI staff by March 2018, which would cover the entire country, is a high priority.

Produce an e-Flora for South African plants by 2020

It is proposed that an online Flora of South African plants can be achieved using existing species descriptions, in particular those that are available in recently published and forthcoming floras (family treatises or regional floras). Descriptions that are not published in family-level treatments or generic revisions can be extracted from regional Floras published by SANBI which will have covered the entire country by 2018. The e-Flora will be linked to the national plant checklist, and should have species descriptions and images for every species, as well as keys.

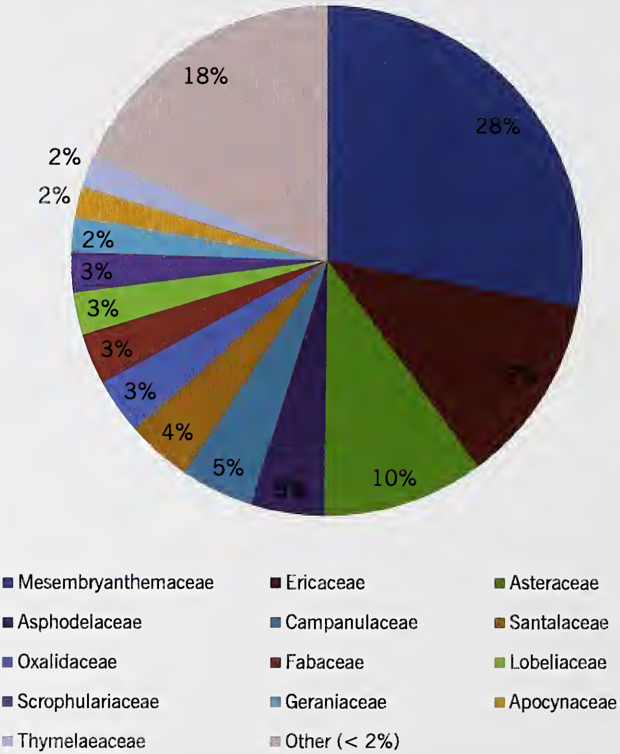


Figure 1.—Proportion of species per family that are Data Deficient for taxonomic reasons.

SO 2: Revisions of plant genera

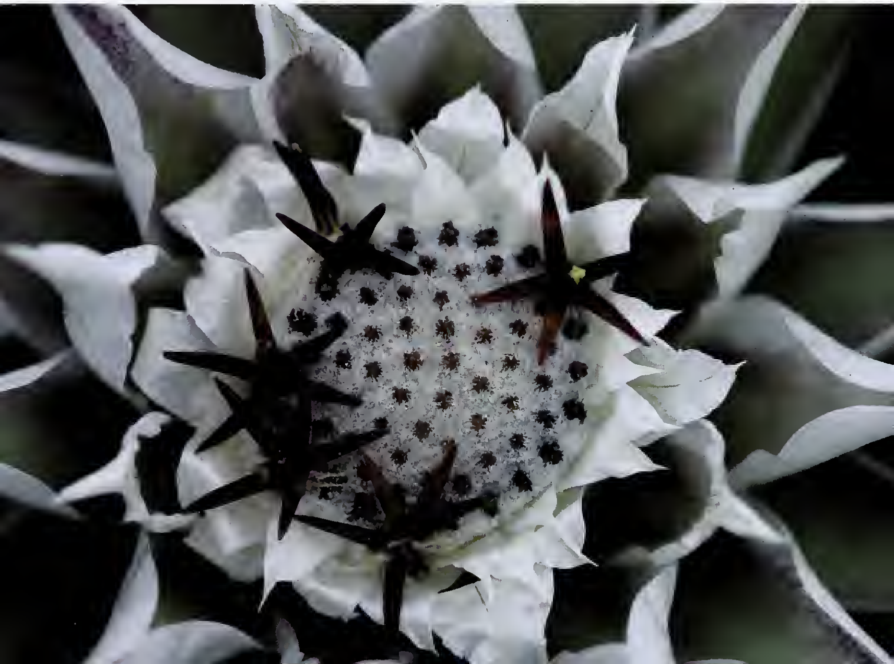
There are approximately 931 currently recognised genera of indigenous plant species in South Africa. Compilation of the Red List was heavily reliant on taxonomic information such as from revisions (Raimondo *et al.* 2009), and in many cases lack of recent revisions was an obstacle to assessing the extinction risk faced by these taxa. Researching plant genera that are in need of revision, especially those that are of conservation or economic importance, will have a positive impact on conservation and the economy. This research includes discovering (inventorying and documenting) our flora.

Five criteria were considered to be indicators of plant genera in need of revision:

1. Date of last revision of the genus.
2. Proportion of plant species in each genus that are categorised as Data Deficient.
3. Proportion of unidentified specimens in each genus.
4. Economic importance of the family to which the genus belongs.
5. Proportion of species in genus occurring in South Africa.
6. From this analysis, a list of plant genera categorised according to their priority for revision was developed for angiosperms, gymnosperms and pteridophytes. Sufficient data are lacking to do a similar analysis for bryophytes. However, certain bryophyte families are treated as priorities in Programme 1.

SO 3: Data Deficient Plant Programme

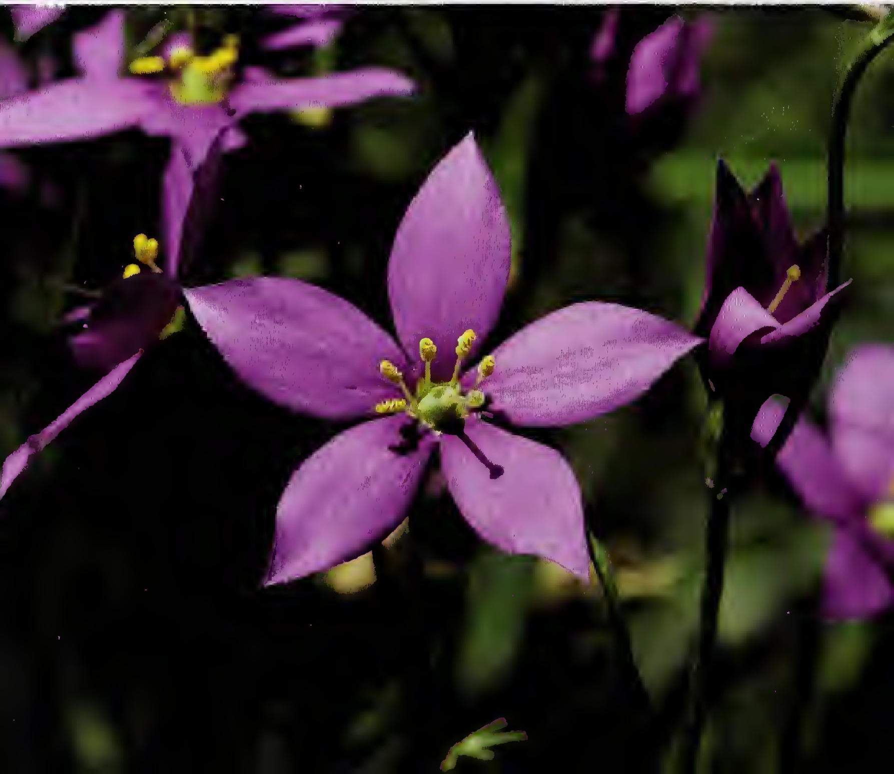
The process of assessing the Red List status of plant species is often hindered because of uncertainties in taxonomic status of the taxon. There are over 1 000 of the plant taxa that are possibly threatened with extinction that have taxonomic problems.



These species are listed as Data Deficient for taxonomic reasons (DDT) and are regarded as priorities for taxonomic research efforts (Victor & Smith 2011) to assist conservation authorities to channel limited financial resources on efforts to protect such species.

The aim of this programme is to solve isolated problems targeting single species of conservation importance in genera that are otherwise not in need of revision and where the species are potentially threatened. Taxonomic problems impede the determination of conservation status of these species, and the species can therefore not receive conservation attention.

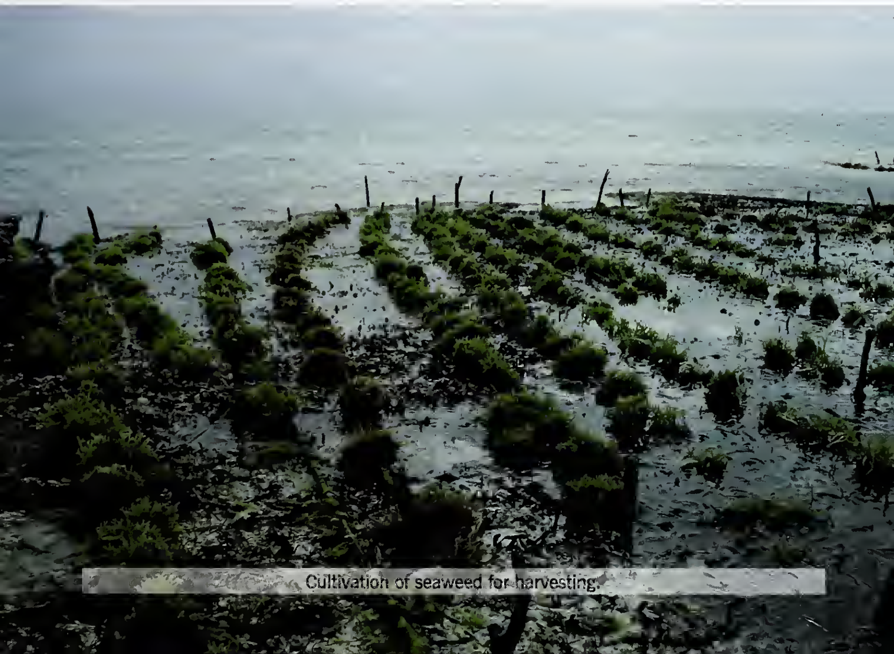
There are 272 taxonomically problematic taxa that are not covered by revisions, which constitute the priority list for this programme. Allowance is made for the possibility that resolving taxonomically problematic species listed under this programme may necessitate revising the genus to which it belongs.



Chapter 7
CONCLUSIONS

Priority objectives and actions across taxa

1. An online and updated taxonomic checklist of South Africa's biodiversity [algae, animals, bacteria and archaea and fungi].
2. An online platform for species information linked to literature and specimen data [all taxa].
3. An online resource for the identification of priority species [algae, animals and bacteria]
4. The establishment of networks of experts to promote (i) information sharing, (ii) collaboration and (iii) the importance of taxonomic research and data [bacteria and fungi].



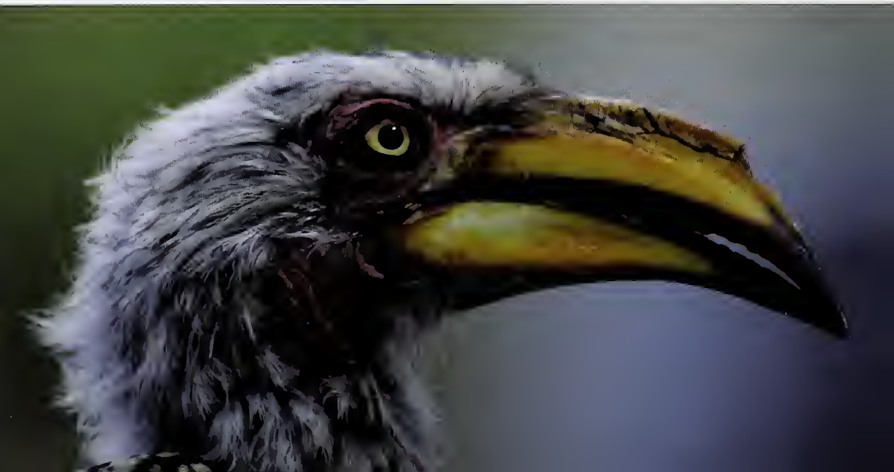
Cultivation of seaweed for harvesting.

Constraints and considerations relating to the implementation of the Biosystematics Research Strategy

While SANBI is mandated with the "co-ordination and promotion of taxonomy in South Africa", its resources remain under pressure and further budget expansion would be required to adequately address the needs of the taxonomy of all biota. In addition, SANBI does not provide funding nationally for taxonomic research which remains a constraint. The new Department of Science & Technology programme for Foundational Biodiversity Information is a potential source of funds, but the objectives and focus of this programme may exclude some priorities included in this document. The broader National Biodiversity Research Strategy includes an objective on taxonomy, but funding for this strategy's implementation requires clarity.

In summary, points raised by the different individuals and groups who worked or commented on components of the Biosystematics Research Strategy highlighted the following considerations:

- SANBI's focus is on plants, but there is a need for a co-ordinating body for other taxa.
- Funding to support the implementation of many of the objectives.
- Shortage of capacity to carry out many of the activities identified, with many experts also having other research interests and responsibilities.
- The need for all taxonomists to buy into the objectives and use the strategy to guide the actions, approaches and research work.



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Research in the fields of taxonomy and biosystematics is fundamental to all other biodiversity research, including conservation biology, agriculture and sustainable use. Following wide consultation, this Strategy for Biosystematics Research in South Africa, the first comprehensive one covering all the major biota occurring in the country, was produced by the South African National Biodiversity Institute. The Strategy provides clear guidelines to taxonomic researchers and funding agencies regarding where research effort and resources should be focussed over the 2013–2018 period to produce maximum benefits to society.

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